TS 4001: Lecture Summary 7

Marine Diesel Engines

SAN ANTONIO LPD 17 (10,000 hp)

Diesel Basics

- Compression of combustion air vs. spark ignition of fuel-air mixture
- Definitions
  - Top Dead Center (TDC) -- highest position of piston in cylinder
  - Bottom Dead Center (BDC) -- lowest position of piston in cylinder
  - Stroke (*S*) -- distance between TDC and BDC
  - Bore (*B*) -- diameter of cylinder
  - Displacement (*D*) -- swept volume of all cylinders in engine
  - Compression Ratio (*CR*) -- ratio of cylinder volume at BDC to cylinder volume at TDC
  - Brake Mean Effective Pressure (*BMEP*) -- indicator of engine loading
  - Piston Speed (V_p) -- average speed of piston during stroke

$$V_p = \frac{SN}{6} \quad (For\ V_p\ in\ feet\ per\ minute)$$

Where: S = *stroke, in.*

N = *revolutions per minute, rpm*

Useful Diesel Equations

- Displacement

$$D = \frac{\pi}{4} n B^2 S$$

Where: n = *number of cylinders in engine*

B = *bore*

S = *stroke*

- Brake Mean Effective Pressure

$$BMEP = 198{,}000 \; C \; \frac{bhp}{DN}$$

Where: *BMEP is expressed in psi*

D = *displacement, cubic inches*

C = *number of strokes per cycle*

bhp = *brake horsepower, hp*

N = *revolutions per minute, rpm*

Useful Diesel Equations (Continued)

- Torque of Output Shaft vs. Power and Rotational Speed

$$T = \frac{33{,}000}{2\pi}\frac{bhp}{N}$$

$Where: \quad T = torque,\ lb\text{-}ft$

$bhp = brake\ horsepower,\ hp$

$N = revolutions\ per\ minute,\ rpm$

- Torque vs. Displacement and BMEP

$$T = \frac{D}{12\pi\ C}\ BMEP$$

$Where: \quad T = torque,\ lb\text{-}ft$

$D = displacement,\ in^3$

$BMEP\ is\ expressed\ in\ psi$

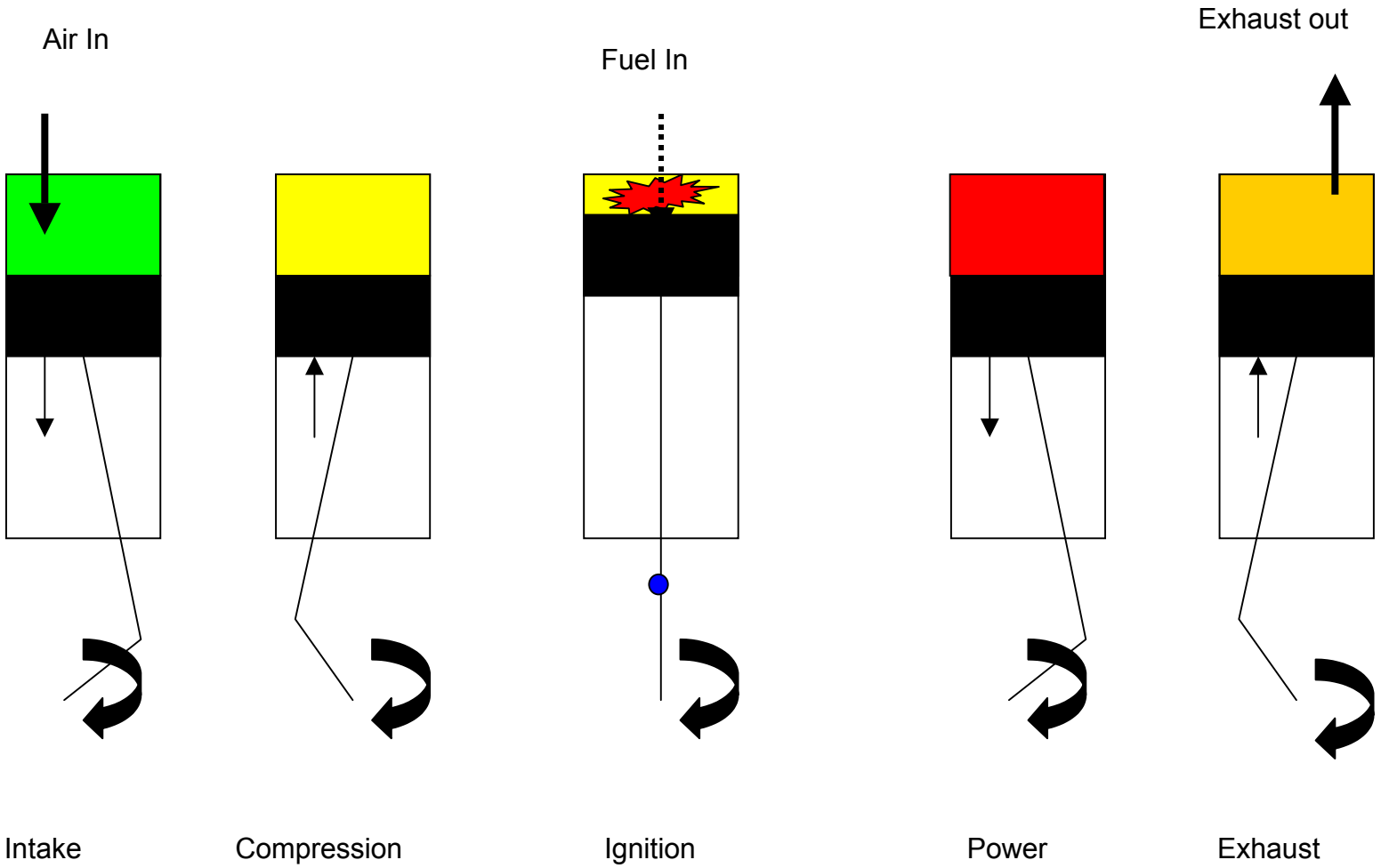
Types of Marine Diesel Engines

- Cycle
  - Two-stroke
  - Four-stroke
- Speed of Rotation
  - Slow speed
  - Medium speed
  - High speed
- Cylinder Arrangement
  - Inline
  - Vee
  - Opposed piston
  - W or X
- Cooling Method
  - Liquid
  - Air
- Air Supply Method
  - Naturally aspirated
  - Scavenged
  - Supercharged (Turbocharged)
- Starting Means
  - High pressure air
  - Hydraulic
  - Electric motor
- Direction of Rotation
  - Reversing
  - Non-reversing

Diesel Cycles

- Two-stroke
  - Compression stroke
  - Power (expansion) stroke
  - Large-bore, slow-speed engines
  - Usually direct coupled
  - Commercial applications
- Four-stroke
  - Intake stroke
  - Compression stroke
  - Power (expansion) stroke
  - Exhaust stroke
  - Smaller bore, medium and high-speed engines
  - Usually geared
  - Commercial and naval applications

4-Stroke Diesel Engine



Diesel Rotational Speeds

- Slow Speed
  - 100 - 200 rpm
  - 5,000 to over 40,000 bhp
  - Generally two-stroke cycle, large bore
  - Commercial applications only
- Medium Speed
  - 400 - 1,200 rpm
  - 1,000 to over 40,000 bhp
  - Generally four-stroke cycle
  - Naval and commercial applications
- High Speed
  - 1,200 - 2,000 rpm
  - Less than 100 to 4,000 bhp
  - Four-stroke cycle
  - Naval and commercial applications

Diesel Cylinder Arrangements

- In-line
  - Cylinders are arranged in a line
  - Generally for eight or less cylinders
  - Require less beam, but more length, than Vee engines
- Vee
  - The other most common arrangement (besides in-line)
  - Cylinders are in two banks, angled to form a “V”
  - Standard for engines with more than eight cylinders
  - Require less length, but more beam, than in-line engines
- W and X
  - More compact, but harder to access, and not commonly used
- Opposed pistons
  - Two-stroke engines with two pistons sharing a common cylinder
  - Usually in-line with one or two crankshafts

Diesel Cooling Methods

- Combustion creates a great deal of heat, and cylinders must be cooled to keep them from exceeding safe material limits
- Either liquid or air is circulated over the outside of the cylinder wall surfaces
- Liquid cooled
  - Most common for marine applications
  - Usually fresh water as primary coolant
  - Heat exchanger transfers heat from primary coolant to seawater secondary coolant
  - Air sometimes used as secondary coolant (like an automotive radiator)
- Air cooled
  - Small engines
  - Useful where sea chest clogging is a problem and it is easy to get air to the engines

Diesel Air Supply Methods

- Naturally aspirated
  - Used with four-stroke cycle
  - Combustion air drawn in as piston moves from TDC to BDC
- Scavenged
  - Two-stroke version of naturally aspirated
  - Combustion air blown in at low pressure (2 to 5 psig) by scavenging blower
- Supercharged (Turbocharged)
  - Combustion air is compressed before entering cylinder
  - Compressed air allows more fuel to be burned, increasing power
  - Compressor either geared or exhaust turbine-driven (turbocharger)
  - Some engines use a two-stage compressor with an air cooler between the stages, or a single stage compressor with an aftercooler between it and the intake manifold
  - Higher density of cooler air allows more fuel to be burned

Diesel Starting Means

- Crankshaft must be externally rotated to initially compress air to ignition temperature and start cycle
- High-pressure air
  - Rotary-type air motor geared to the crankshaft
  - Air also can be fed directly into cylinders through air-starting valve
- High-pressure hydraulic fluid
  - Hydraulic motor geared to the crankshaft
- Electric motor
  - Electric motor geared to the crankshaft
- In all cases, starting motor is disengaged once engine starts and maintains cycle

Diesel Rotational Direction

- Unidirectional
  - Engine only rotates in one direction
  - Must use either a reversing gear or a CRP propeller for reverse power
- Direct reversing
  - Engine can be stopped and restarted in opposite direction
  - Process to reverse usually automatic

Torque Characteristics

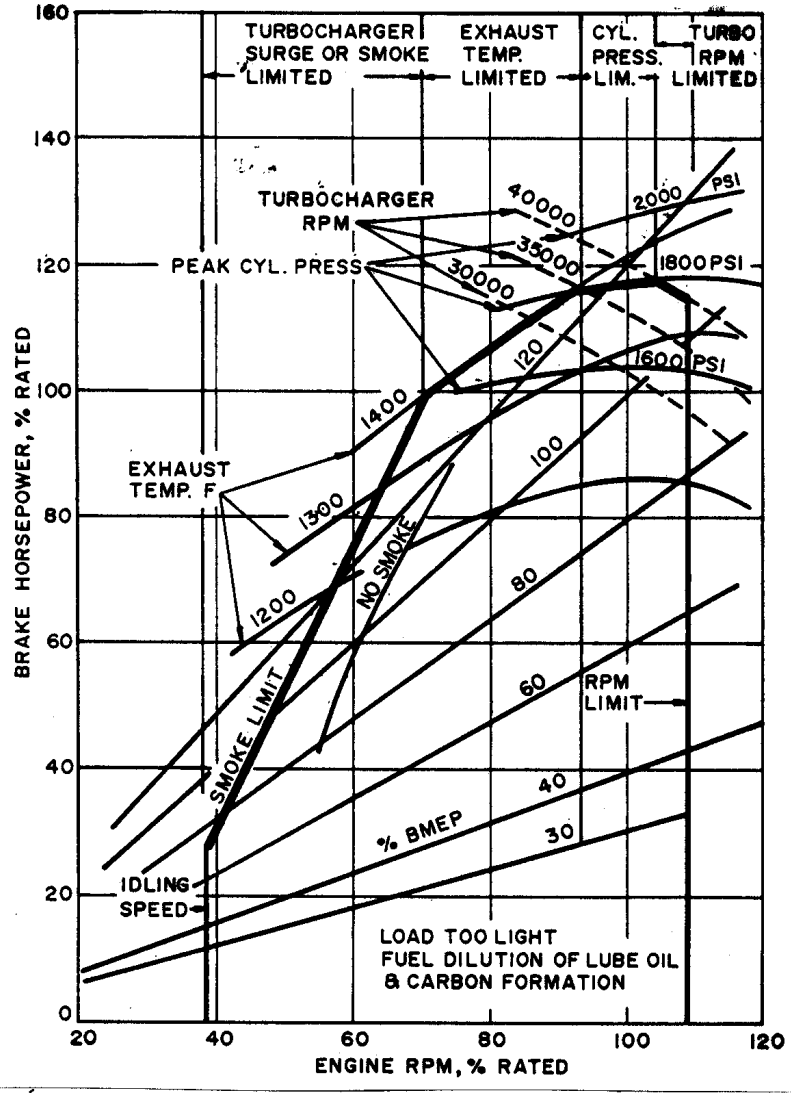
- Torque is controlled by quantity of fuel injected into the cylinders each cycle
- Limitations on maximum torque produced
  - Smoke
  - High Stress
  - High Temperature
- Diesels are relatively constant-torque machines
  - Torque rises to about 110% of full-load torque as speed is reduced from full-speed rpm through 55% speed, and then drops back to full-load as speed is reduced further
- Torque characteristics may be modified for high-torque applications
  - Increase amount of fuel injected as speed is reduced, raising torque to as high as 140% full load condition

Horsepower Characteristics

- At constant throttle, diesel engine horsepower is almost a linear function of engine speed
- Power at any speed limited by different constraints
  - At lower speeds, horsepower is principally limited by smoke
  - At some mid-point speed, maximum exhaust temperature governs
  - As speed nears full-rated, power is limited by maximum cylinder pressure
  - Above full rated, maximum rpm begins to limit power
  - Shape of curve is basically the same for all engines, but limit points differ based on engine design
- Other factors which may limit horsepower include:
  - Temperature of pistons, cylinders, heads, and valves
  - Bearing loads
  - Lubrication oil breakdown
  - Turbocharger rpm

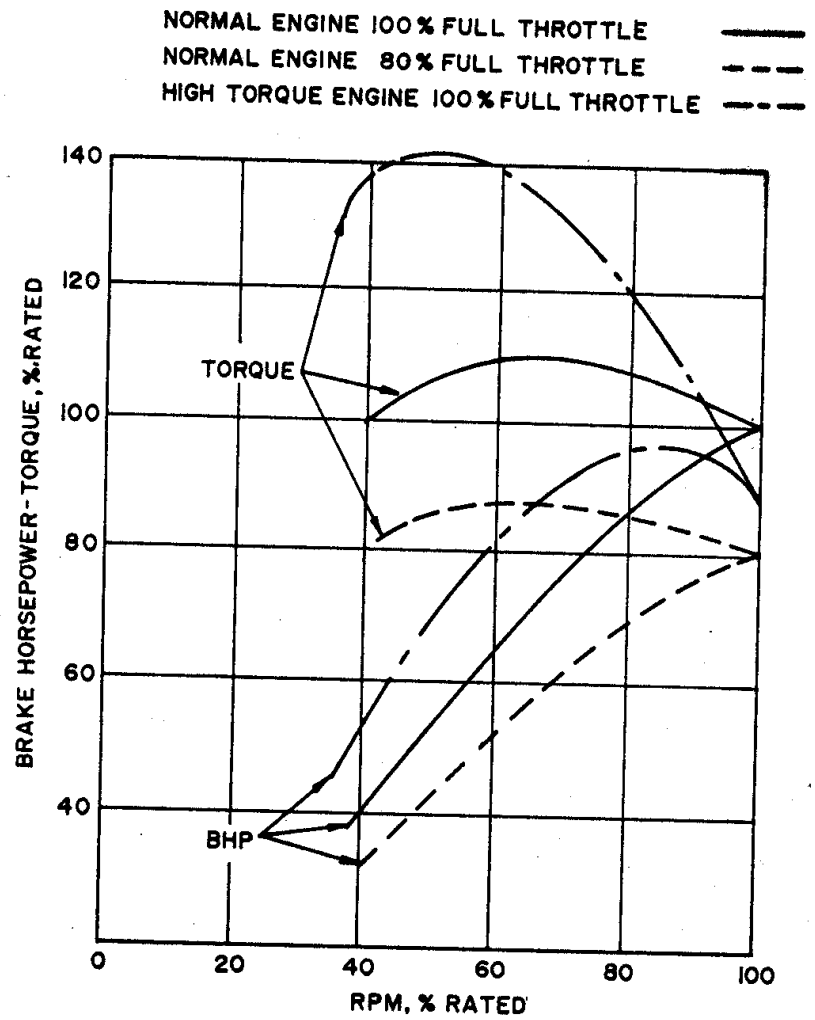
Typical Graphs

- General BHP/RPM diagram.
- Note the various limits on engine performance.
- BHP is increasing linearly in RPM for constant BMEP.



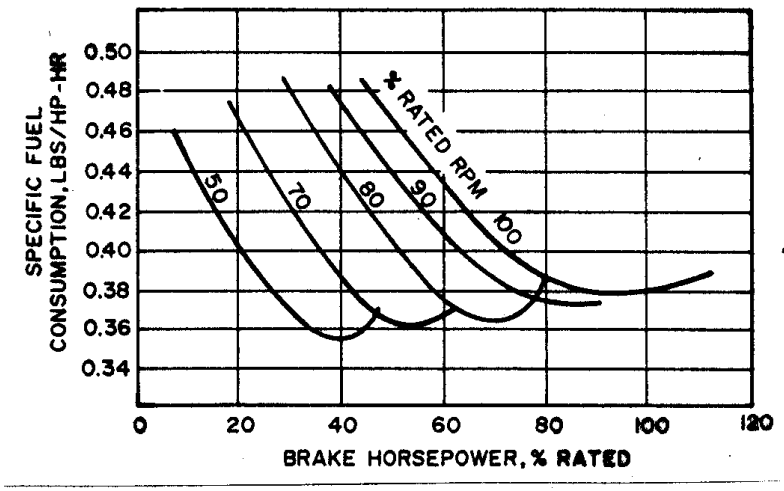
Engine Torque Characteristics

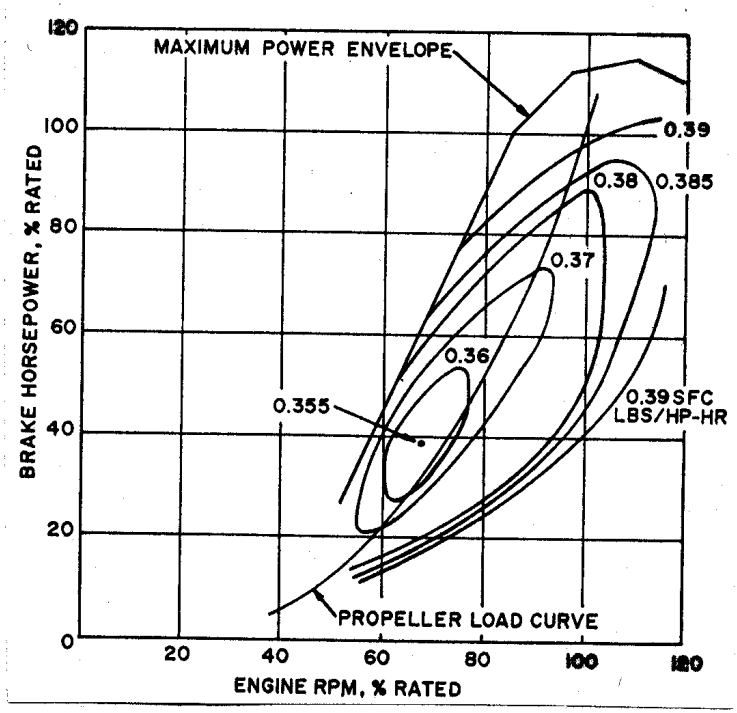
- Torque is relatively constant for a given engine throttle.



Fuel Consumption

- Diesels have relatively constant fuel consumption throughout their power range, especially compared to simply-cycle gas turbines
- Two common graphs of fuel consumption
  - SFC vs. BHP at constant speed (fishhook curves) -- useful for diesel-generator sets where the speed is constant
  - SFC vs. BHP and RPM (fuel map) – useful for propulsion applications, where engine speed varies with horsepower





Engine Speed

- Idling speed is the lowest speed that a diesel engine may be operated
  - Generally about 30% of full-rated speed, but high-speed engines may idle at 50% and larger engines may idle at 25% full-rated speed
  - Idling speed associated with fuel injection, combustion, and inertia characteristics of the engine and gears
- Other systems affected by low speed operation of diesel engine
  - Cooling and lube oil pumps driven by belts or gears off the crankshaft
  - If speed is too low, speed of these pumps may not be sufficient
  - If low speed operation is necessary, pumps may be specially geared or driven by other means
- Combustion can be unsatisfactory at light-loads
  - Unburned fuel will dilute lube oil which increases wear on parts
  - Carbon and lube oil can accumulate in exhaust passages, causing visible smoke when load is increased

Marine Diesel Ratings

- Manufacturers have different ratings based on application of engine and expected loading
  - Maximum -- ideal conditions
  - Intermittent Duty -- 85% to 90% maximum
  - Continuous Operation -- 70% to 75% maximum
  - Rating categories differ between manufacturers
- Necessary to apply correction factors based on environmental conditions
- Important to consider power reductions for items not included in rating
  - Reverse and reduction gears
  - Battery charging generators
  - Air compressors
  - Hydraulic system pumps
  - Bilge pumps

S.E.M.T. Pielstick Diesels

- PA6-280 Medium Speed Engines
  - 6PA6L, 8PA6L, 12PA6V, 16PA6V, 18PA6V, 20PA6V
  - 280mm x 290mm (Bore x Stroke)
  - 1,000 rpm (1,050 for 18 and 20-cyl)
  - 400 hp/cyl (440 for 18 and 20-cyl)
  - 9 - 13 lbs/hp
- PA6 STC (Sequential Turbocharger)
  - STC uses one turbo for powers below 50%, and second identical turbo for powers above 50% nominal
  - 12PA6V280 STC, 16PA6V280 STC, 20PA6V280 STC
  - 280mm x 290mm (Bore x Stroke)
  - 1,050 rpm
  - 440 hp/cyl
  - About 9.5 lbs/hp
  - French La Fayette has 4 x 12PA6V280 STC in a CODAD plant

S.E.M.T. Pielstick Diesels (Continued)

- PA6B STC Variant
  - 12PA6BV280 STC, 16PA6BV280 STC, 20PA6BV280 STC
  - Stroke lengthened from 290mm to 330 mm
  - Power increased from 440 hp/cyl to 550 hp/cyl with about 8.5 lbs/hp
- PC2.6 and PC2.6B Medium Speed Engines
  - 12PC2.6V400, 16PC2.6(B)V400, 18PC2.6(B)V400, 20PC2.6BV400
  - 400mm x 460mm (b x s) with 500mm stroke for “B” variant
  - 520 rpm (530 for “B”)
  - 747 hp/cyl (857 hp/cyl for “B”) and about 17.5 lbs/hp
  - LSD-41 Class has 4 x 16PC2.5V400 engines
- PC4.2 Medium Speed Engines
  - 10PC4.2V470, 12PC4.2(B)V570, 18PC4.2(B)V570
  - 570mm x 620mm (b x s) with 660mm stroke for “B” variant
  - 400 rpm (430 for “B”)
  - 1650 hp/cyl (1800 hp/cyl for “B”) and between 22 and 26 lbs/hp

MTU Marine Diesels

- Highly tuned, low weight medium and high speed engines
- From six to 20 cylinders, all “Vee” except the six cylinder
- From 109 hp at 2,400 rpm to 9,920 hp at 1,300 rpm
- Four ratings for marine applications (1A, 1B, 1D, 1DS)
- Classification System

20 V 1163 TB 93

- 20 cylinders
- Vee arrangement
- 11.63 L displacement per cylinder
- T for Turbocharged (A for aspirated)
- B for external cooling (C for internal, D for air-to-air, E for split, etc.)
- 9 for marine applications (can range from 5 to 9 for marine)
- 3 is design index

Caterpillar Diesels

- Medium to high speed propulsion engines and SSDG prime movers
- Heavier duty
- From four to 16 cylinders, both in-line (4 and 6) and Vee
- From 205 bhp at 2,400 rpm to 7,270 bhp at 1,000 rpm
- 3100, 3300, 3400, 3500, and 3600 series
- Wide range of generator sets (up to 5,200 kW)
- About 8 lbs/hp for 3500 series

Additional Reading

- *Marine Engineering* (R. Harrington, ed.)

  Chapter VII: Medium and High-Speed Diesel Engines